1. **Introduction (drawn from Project Pitch)**
    a. **Describe idea (get interest of reader)**
        i. We aim to build a unique musical instrument (specifically a synthesizer) using the Raspberry Pi Pico. We want how the user interacts with our instrument to be distinctive from most other instruments, so we decided to construct an octave of force-sensitive resistors for the user to push. The readings from these inputs will be sent through a synthesizer on a chip controlled by the Raspberry Pi Pico, and the user will also be able to customize the sound of the instrument they play on the fly by varying several sliders and knobs.
    b. **Compare with existing solutions**
        i. **At least two references to:**
            1. **Technical Papers (IEEE Explore)**
                a. Our first reference is to *Music Synthesis Using Real Time Digital Techniques*
                    i. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1455942
                b. Our second reference is to *Music Synthesis on Different Musical Instruments Using ARM Cortex-M4F Microcontroller*
                    i. https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8903918
            2. **OR Patents (www.patents.google.com)**
                a. Electronic musical instrument
                    i. https://patentimages.storage.googleapis.com/f0/94/60/c1164f0ed82933/US6005181.pdf
    c. **Can include addition references (including websites)**
        i. https://www.thingsmadesimple.com/2023/01/02/ym3812-part-2-face-reveal/
            1. We used this site to understand how other people have wired microcontrollers up to the Yamaha synthesizer chip we are using. Our project is distinct from the one on this website in all other respects. We are using a different MCU architecture, and we are not focusing on MIDI but rather on using ADCs to read from Force Sensitive Resistors (FSRs)
    d. **How is your idea different/better?**
        i. Our idea is different because we combine ideas from several of these patents. We are using a digital FM synthesizer as described in the first IEEE paper, but we are also using force-sensitive resistors as described in the patent we found. Our goal is to build an easy-to-play and inexpensive

musical instrument that operates in an untraditional way. Unlike the patent we found, however, we don't intend to make our instrument a MIDI controller; it will just be a standalone instrument driving a synth chip.

e. **Who are your stakeholders?**
    i. Our stakeholders are musicians who want to experiment with an untraditional instrument or synthesizer. Our goal is to make an instrument that is easy enough to play without any advanced technical knowledge, which also sounds good.

2. **Requirements**
    a. **Functional Requirements**

Must-have:

F1) When the force-sensitive resistors (FSRs) are pressed, the synthesizer sound output shall emit a distinct tone (or musical note) for each FSR.

F2) When the volume slider is adjusted, the volume shall correspondingly increase or decrease. When the "attack," "decay," or "pitch bend" sliders are adjusted, the Yamaha synthesizer chip's internal registers shall be adjusted accordingly.

Nice-to-have:

F3) The volume of the synthesizer sound output tone (or musical note) for a given FSR shall depend upon the user's pressure applied to a given FSR.

F4) When the instrument cycle button is pressed, the synthesizer's current instrument should change to a new one. When each instrument changes, the RGB LED should become a distinct color.

F5) When the "custom instrument" is selected, the "attack" and "decay" features of the synthesizer shall be controlled by the sliders and potentiometers.

F6) The power indicator LED shall turn on when the power switch is turned on and off when the power switch is turned off.

b. **Nonfunctional Requirements**

Must-have:

NF1) The synthesizer should support up to 9-tone polyphony.

NF2) The synthesizer shall have 12 FSRs, with each FSR mapped to a specific musical note on a standard octave.

Nice-to-have:

NF3) The synthesizer should support several instrument modes, including piano, organ, wind, and custom instrument.

NF4) The synthesizer should support "pitch-bending," where the user can adjust a potentiometer and cause all of the output tones to vary by at least 150 Hz.

NF5) The FSRs should have no more than 1-second latency between detecting pressure changes and the tone output changing. The synthesizer shall take no more than 10 seconds from when the power switch is turned on to being in a playable state. The instrument cycle button shall take no more than 2 seconds to switch between instruments.

NF6) There should be no audible interference noise in the sound output from the speaker. The interference noise should be less than 25 dB.

3. Budget – Bill of Materials (BoM)

4. Main parts, sources, cost

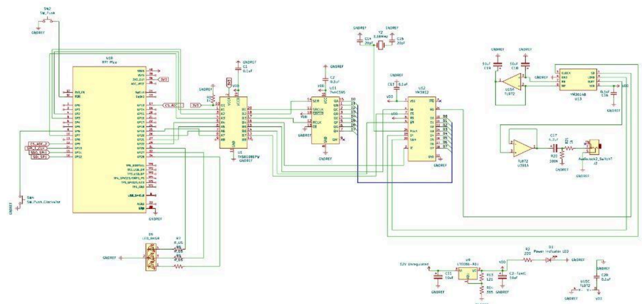
Order Information - *Green_Owens_Satalof*

Qty	Unit	Part #	Description	Web Link (URL)	Unit Price	Total Cost
1	each	203452539298	Y3014B DAC	https://www.ebay.com/itm/203452539298?_skw=ym3014&itmmeta=01JBMKQGF2VAQZH1GP9PQ82GDF&hash=item2f5eb761a2:g:kXUAAOSwBfNgn0nK&itm	$15.00	$15.00
1	each	335364161492	YM3812 OPL2 Sound Processor	https://www.ebay.com/itm/335364161492?_skw=YM3812&epid=1223813371&itmmeta=01JBM6RHFAPFKACDDSJQFXP76W&hash=item4e1542ffd4:g:iVsAAC	$16.00	$16.00
1	each	1875	Logic Level Shifter	https://www.adafruit.com/product/1875	$3.50	$3.50
1	each	2130	Audio Amplifier Board	https://www.adafruit.com/product/2130	$4.00	$4.00
5	each		Slide Potentiometer	https://www.adafruit.com/product/4272	$1.95	$9.75
14	each	166	Force Sensitive Resistors	https://www.adafruit.com/product/166	$3.95	$55.30
1	3 pack	450	74HC595 Shift Register	https://www.adafruit.com/product/450	$2.95	$2.95
1	Pack of 5	EI14/EI-14	Isolation Transformer	https://www.amazon.com/HiLetgo-EI-14-Coupling-Isolation-Transformer/dp/B073PXK2RX/ref=sr_1_1_sspa?dib=eyJ2IjoiMSJ9.AKAMZraVKIH_SX_e3FrftOKIUZ	$6.50	$6.50
1	Pack of 10	B09BCT2T8W	Perfboard	https://www.amazon.com/Prototype-Perfboard-Breadboard-Electronic-Experiments/dp/B09BCT2T8W?dib=eyJ2IjoiMSJ9.wh_2piAiI9y89fFEGhSOfbWkGWAv-PM	$8.00	$8.00
1	300 pack	B0BVTDP29W	Assorted Springs	https://www.amazon.com/Dianrui-Compression-Assortment-Mechanical-K-P-051-300/dp/B0BVTDP29W?crid=KJRU599OYW01&dib=eyJ2IjoiMSJ9.4XAfKyAfTj	$10.00	$10.00
1	each	2218003	Wall Wart Power Supply	https://www.jameco.com/z/DFU120200RU0070-2-1-Jameco-ReliaPro-12-Volt-2-Amp-24-Watt-Unregulated-Wall-Adapter_2218003.html	$11.59	$11.59
3	each	C315C200J3G5TA	20pF C0G Capacitor	https://www.mouser.com/ProductDetail/KEMET/C315C200J3G5TA?qs=h3%2Fj8evtlm0%2FLY3%2FA5wDRw%3D%3D	$0.38	$1.14
2	each	LFXTAL032257Bulk	Crystal Oscillator 3.58MHz	https://www.mouser.com/ProductDetail/IQD/LFXTAL032257Bulk?qs=e4%2FAndAAwgIbIOlj9s9BBA%3D%3D	$0.52	$1.04
1	each	PJ-002B	Barrel Jack	https://www.digikey.com/en/products/detail/same-sky-formerly-cui-devices/PJ-002B/96965	$0.66	$0.66
10	each	C326C104K3G5TA	0.1 uF C0G Capacitors	https://www.digikey.com/en/products/detail/kemet/C326C104K3G5TA/6657051	$0.40	$3.99
2	each	LT1086CT#PBF	Linear Regulator	https://www.digikey.com/en/products/detail/analog-devices-inc/LT1086CT-PBF/891238	$7.47	$14.94
2	each	LM358P	LM358 Op Amp	https://www.digikey.com/en/products/detail/texas-instruments/LM358P/277042	$0.23	$0.46
2	each	MCP3008-I/P	8 Channel Analog to Digital Converter	https://www.digikey.com/en/products/detail/microchip-technology/MCP3008-I-P/319422	$3.12	$6.24
2	each	TAP106J025CCS	Tantalum Input Capacitor	https://www.digikey.com/en/products/detail/kyocera-avx/TAP106J025CCS/1471109	$1.73	$3.46
10	each	RCRBD100K1TC11300T	Input Electrolytic Capacitor	https://www.digikey.com/en/products/detail/elna-america/RCRBD100K1TC11300T/7724465	$0.17	$1.66
3	each	SFR16S0003650FR500	LDO Programming R2	https://www.digikey.com/en/products/detail/vishay-beyschlag-draloric-bc-components/SFR16S0003650FR500/594376	$0.22	$0.66
3	each	SFR16S0001210FR500	LDO Programming R1	https://www.digikey.com/en/products/detail/vishay-beyschlag-draloric-bc-components/SFR16S0001210FR500/594277	$0.22	$0.66
4	each	7427605	Ferrite Bead	https://www.digikey.com/en/products/detail/w%C3%BCrth-elektronik/7427605/21719288	$0.15	$0.60
2	each	TL072IP	TL072 Op-Amp	https://www.digikey.com/en/products/detail/texas-instruments/TL072IP/563039	$0.74	$1.48
2	each	MFR50SFTE52-100K	100K Resistor	https://www.digikey.com/en/products/detail/yageo/MFR50SFTE52-100K/9151029	$0.11	$0.22
2	each	MFR50SFTE52-1K	1K Resistor	https://www.digikey.com/en/products/detail/yageo/MFR50SFTE52-1K/9151157	$0.11	$0.22
6	each	2276439	Slide Potentiometer	https://www.jameco.com/webapp/wcs/stores/servlet/ProductDisplay?storeId=10001&langId=-1&catalogId=10001&pa=2276439&productId=2276439	$1.39	$8.34

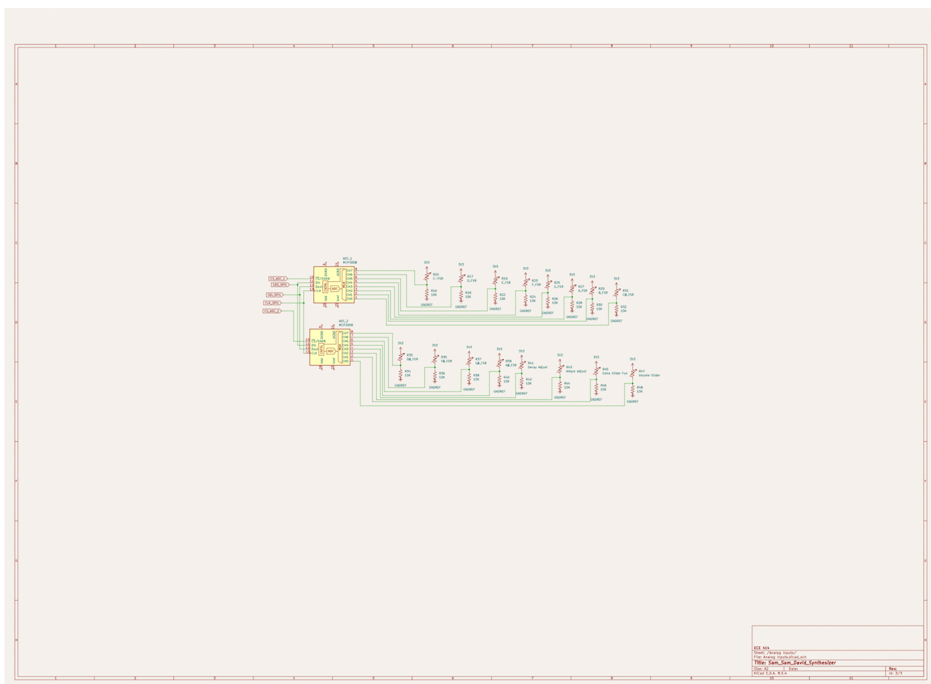
a. The figure above shows the BOM we submitted. The link below shows more specific details.

b. https://docs.google.com/spreadsheets/d/1wWx7NoN0niOg4OyxRgSEuLQ73sbtSEusBygbHS5XZsA/edit?gid=1407191880#gid=1407191880

5. Schematic diagrams of hardware



a.


ECE 414
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Title: Sam_Sam_David_Synthesizer
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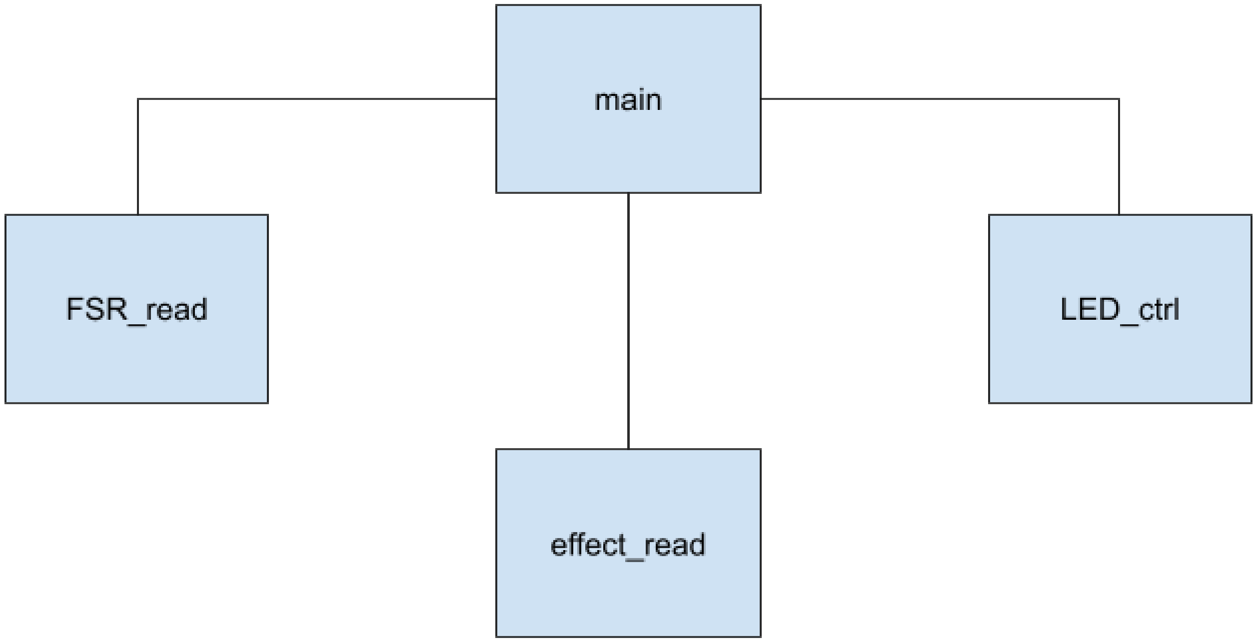
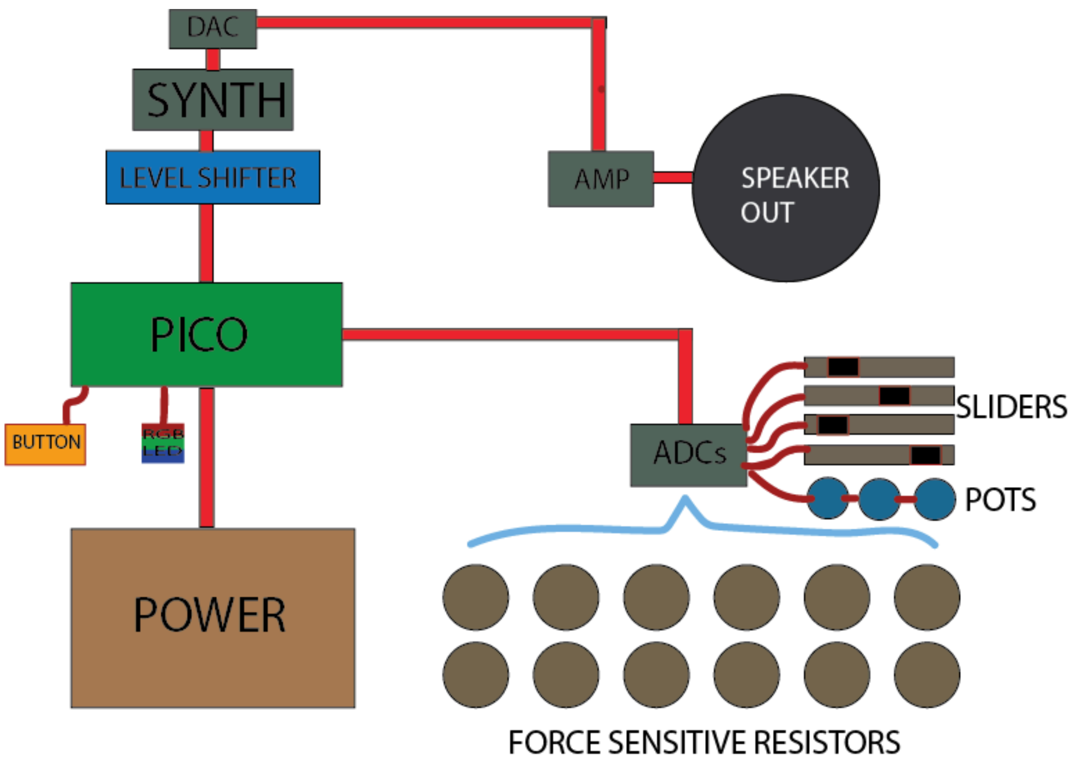
Rev:
KiCad E.D.A. 8.0.4
Id: 3/3

b.

6. **Block diagram of software**

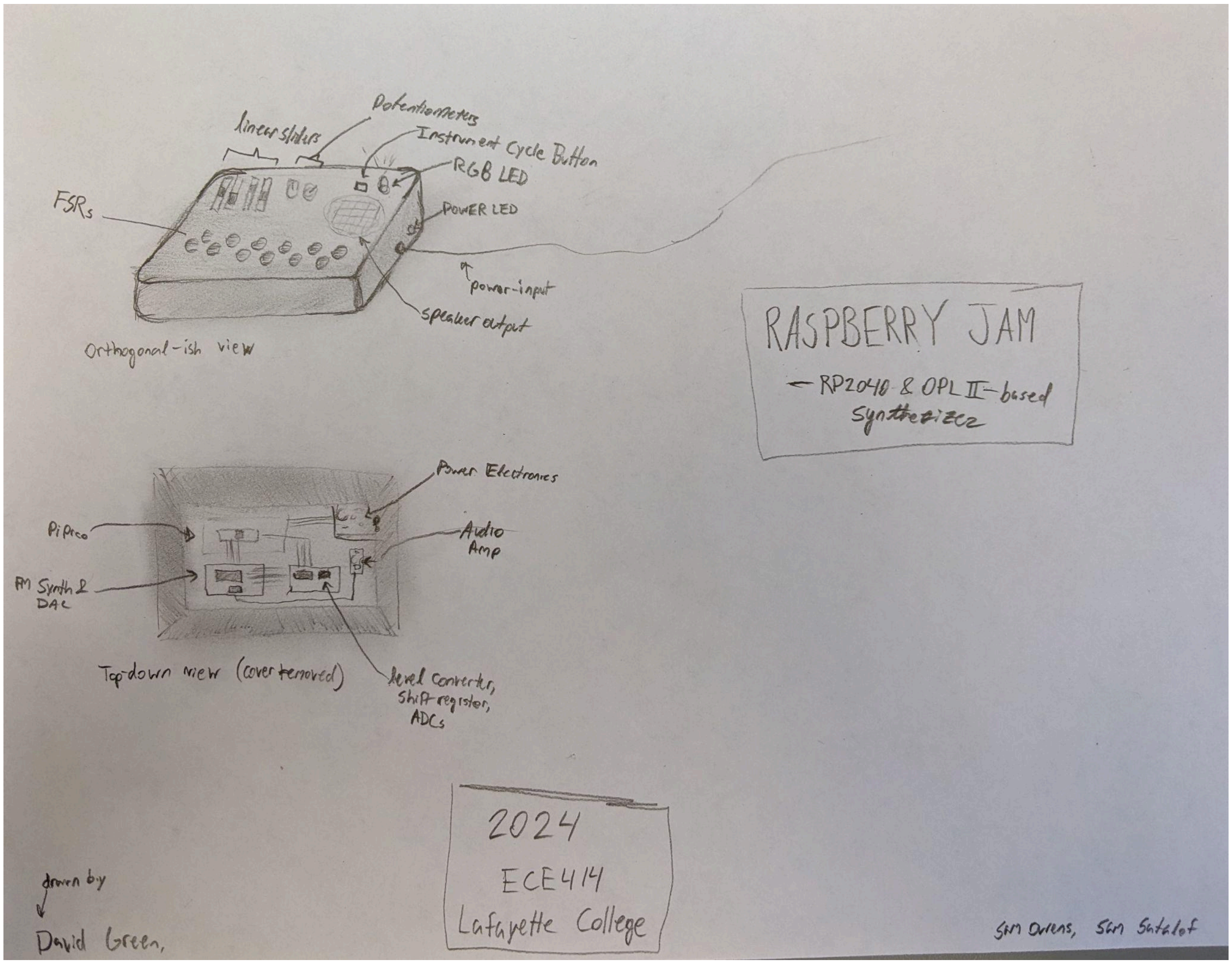


7. **Diagram(s) of a physical system**



    a.

8. **Sketches of physical design**



9. **Description of how it works**
    a. The user presses the force-sensitive resistors (FSRs), and the resistance changes as a result. The analog-to-digital converters (ADCs) hooked up to the Pico take analog readings from each FSR and send them back to the Pi Pico. The Pi pico takes each reading from the FSRs and writes these values to registers stored in the Yamaha Synthesizer chip. When the registers in the Synth chip are written to, it changes parameters inside the chip and produces musical tones. The user can cycle through several different preset instruments by pressing a push button on the instrument. These presets write predetermined values to the registers inside the synth chip that cause it to make tones sound like specific instruments. When the user cycles through these instruments, an RGB LED changes color to indicate the selected instrument. One option for the user is to choose the “custom instrument” mode. When this mode is selected, the register values for determining synthesizer characteristics such as “attack” and “decay” are not hard-coded but instead become tweakable values determined by some linear sliders and potentiometers

connected to the Pico through the ADCs. The sound produced by the Synthesizer chip is digital. So, this value is sent through a serial digital-to-analog converter (DAC) chip, which creates analog tones from the synthesized sounds. We then run the output of the DAC through an audio amplifier connected to a speaker, producing the noises that the user will hear.

b. The instrument is powered by a 12V power supply connected to the mains. We are lowering the power to 5V for the Yamaha chips and 3.3V for the Pi Pico. There is also a power indicator LED to show the user when the system is powered on.

10. Test plan

a. How will you verify requirements?

i. We will verify requirements using a traceability matrix and check off each requirement from the matrix as completed. We will only check any of the quantitative requirements once we have obtained a measurement that meets our defined criteria.

b. How will you measure success?

i. Some characteristics of success are measurable, while others are subjective, such as “Does it sound nice?” We view a successful implementation of this final project as leaving us with a playable musical instrument. The instrument should be easily playable by anyone, even if they are not an ECE. We need to meet all of the project requirements described with the word “shall” in them, and while it would be nice to meet the criteria that say “should,” we aim to meet these as time permits. We will still be successful if we only achieve the “must-meet”/”shall” requirements as defined above.

ii. We will measure success by whether or not we check off all of the “must-have” boxes in our traceability matrix.

11. Describe tests using the format from labs.

T1: Demonstrate ability to get valuable readings from the FSRs by taking consecutive measurements from all 12 FSRs. This must be done consecutively and not simultaneously because the ADC readings are muxed. Print the live results of these measurements to the UART.
Fulfilled Requirements: F1, F3, NF2

T2: Play arbitrary tones specified in a program to demonstrate adequate control of the Yamaha Synthesizer chip. Make the synthesizer chip play a few notes from a song.
Fulfilled Requirements: F1

T3: Take the readings from all 12 FSRs and direct them into the Yamaha Synthesizer chip. When the user interacts with the FSRs, the Yamaha synthesizer chip should allow at least nine tones to be played at once.

Fulfilled Requirements: F1, NF1, NF2

T4: While playing the arbitrary notes from T2, take analog readings from the sliders and potentiometers on the synthesizer and use them to control the attack, decay, and pitch bend functions of the Yamaha synthesizer chip. Use an instrument tuner app to verify that the pitch bend function can vary the output tone by at least 150 Hz.
Fulfilled Requirements: F2, F5, NF4

T5: Ensure that the user can vary the volume of their synthesized tones with all 12 FSRs so that more pressure results in a louder tone.
Fulfilled Requirements: F3

T6: Implement several different-sounding instruments and play the arbitrary song from T2 through these instruments. Ensure the “change instrument” button allows users to cycle through these predetermined instrument presets. When the user hits the “custom instrument” preset, ensure that the attack, decay, and pitch bend liner sliders define the custom instrument.
Fulfilled Requirements: F2, F4, F5, NF3, NF4

T7: Ensure that the power LED turns on and off when the power switch is turned on and off.
Fulfilled Requirements: F6

T8: Use a slow-motion video camera and a stopwatch to verify that the latency between pressing an FSR and hearing a change in tone is less than 1 second. Use the exact stopwatch to ensure that instruments change in less than two seconds after pressing the instrument cycle button. Use a stopwatch to verify that the synthesizer is playable less than 10 seconds after turning the power switch on.
Fulfilled Requirements: NF5

T9: Use a sound pressure level metering app on a smartphone to listen to the sound emitted by the synthesizer when no notes are actively being pressed. Confirm that the sound emitted by the synthesizer is less than 25dBA when the synthesizer is not being interacted with by the user.
Fulfilled Requirements: NF6

12. Include a traceability matrix.

Requirements													Test Result
	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**NF1**	**NF2**	**NF3**	**NF4**	**NF5**	**NF6**	
T1	X		X					X					?
T2	X												?
T3	X						X	X					?
T4		X			X					X			?
T5			X										?
T6		X		X	X				X	X			?
T7						X							?
T8											X		?
T9												X	?

13. Estimated schedule

- Get readings from the ADC on a breadboard (By the 20th)

- Get readings from the ADC and 12 FSRs, four linear sliders, and four potentiometers (By the 22nd)
- Build a working Power Supply on the perf board (By the 22nd)
- Get the Synth chip, DAC, level shifter, amp, etc., to make noise on a breadboard (By the 26th)
  - Play a simple arbitrary song/series of tones to prove we have adequate synth control
- Get the Synth chip to make noise on a breadboard **AND** react to the FSRs and ADC (By the 26th)
- Transfer the working breadboard circuitry to a perf board and solder it all together (By December 4th)
- Build a nice-looking 3D printed or laser-cut enclosure for the project (By December 4th)
  - Have a design planned out by:
  - Physically assemble the design:
- Add support for multiple instruments (By December 6th)
- Add support for custom instruments (By December 6th)
- Refine capabilities of the synthesizer –polyphony, tuning calibrations, etc. (By December 6th)
-

Deadlines:

14. Who is responsible for what tasks?

15. Est. person-hours for each task and

   a. Approx. group total = ~60 ×{Group size <int>}